INTRODUCTION

The air pollution index (API) and the air quality index (AQI) have been commonly applied in Vietnam and abroad. These indices are aggregated from the individual indices (sub-indices), calculated from daily standards (1 h, 8 h and 24 h) or yearly standards (24 h, year) and they form a simple formula for overall assessment of the level of pollution/air quality. There are three main methods to build the daily index API/AQI:

Using the highest value of the individual indices [1-3]. This method was used by the US Environmental Protection Agency [4]. Similar methods were also used by Hong Kong Environmental Protection Department [5], State Environmental Protection Administration of China [6], Singapore National Environment Agency [7], Hoang et al. [8], Vietnam Environment Administration [9], Nghiem et al. [10]. However, these indices have several limitations as thresholds and hierarchy rating is self-regulation (5-7 levels); Some indices take into account the weight which is subjectively scored by the expert's criteria; indices do not take into account the total amount of pollution from individual indices; When expanding to the number of parameters n ≥ 2 contained in the country's toxic gas standards, it is necessary to build up the lower and higher breakpoints, or complex search schemes that are not conducive to apply.

Using the summation of the individual indices, according to the method of the former Soviet Union [11]. There are only three levels of the rating hierarchy; no weight.

Using the geometric means of the individual indices [12] or arithmetic means of the individual indices [13]. Similar to the first method, the rating scale of this approach is also self-regulation; It does not take into account the total amount of pollution from individual indices; The weight of each parameter is in accordance with the expert grading method, so subjective. The index has a "virtual" effect including eclipsing and ambiguity, which means that in some cases the index does not match the actual results.

The article aims at proposing a new method to overcome some limits of API/AQI as mentioned above.

Relative Air Pollution Index (RAPI) - A New Method for Aggregate Air Pollution Assessment

Pham Ngoc Ho*

Research Center for Environmental Monitoring and Modeling (CEMM), VNU University of Science, 334 Nguyen Trai Street, Thanh Xuan district, Hanoi, Vietnam

ABSTRACT

In this article, the author proposes a new method for integrating the relatively individual pollution indexes into an aggregate index called Relative Air Pollution Index (RAPI). This index has overcome some limitations of the air pollution index (API) or air quality index (AQI) which is being used in countries around the world as well as in Vietnam. Using the automated observation data recorded at Nguyen Van Cu station in Hanoi in 2016 to test the RAPI calculations, the results show that RAPI is conformed to the ambient air pollution level at Nguyen Van Cu station.

Keywords: Indices, Aggregates, Weights, Thresholds and scales, Frequency of pollution
MATERIALS AND METHODS

Data

The automatically monitored data for successive 12 months in 2016 at the monitoring station Nguyen Van Cu [14] were used to calculate the daily RAPI. The monitoring station is from HORIBA-Japan. The station is located at coordinates 21º02'56.3"N, 105º52'58.8"E and 2.5 m from the ground; detector is 3-3.5 m above the ground. The width of pavement is 5 m (adjacent to the highway).

The selected basic parameters (μg/m³) are O₃, PM₁₀, CO, SO₂, NO₂ and the processing of input data to calculate average concentration value of each parameter (1 h average, 8 h average and 24 h average) is conducted according to the standard/regulation of each country. As for average hourly data, the highest concentration value of each parameter monitored during 24 h of a day was used to calculate individual index qi (1 h); As for 8 h average data, the average values of 8 observations (there are three 8 h average values per day) were taken, then the highest value from these 8 h average values was used to calculate the individual index qi (8 h); as for 24 h average data, the average value of 24 observations was taken to calculate individual index qi (24 h).

METHOD OF BUILDING DAILY RELATIVE AIR POLLUTION INDEX RAPIₙ

Approach

The level of air pollution at an observation point at one time point is the concomitant effect of n parameters, so the aggregate index P is determined by the formula:

\[ P = \sum_{i=1}^{n} W_i q_i \]  

(1)

\[ q_i = \frac{C_i}{C_i^*} \] (Relatively individual index)  

(2)

\[ C_i = \text{monitoring concentration of parameter } i; \quad C_i^* = \text{permissible standard of parameter } i; \] \[ n = \text{number of parameters}; \]

\[ W_i = \text{Important weight of parameter } i \text{ (based on standard of 1 h, 8 h and 24 h)} \]

1st case: \( C_i < C_i^* \) mean \( q_i < 1 \) – no pollution  

(3)

2nd case: \( C_i = C_i^* \) mean \( q_i = 1 \) – borderline pollution  

(4)

3rd case: \( C_i > C_i^* \) mean \( q_i > 1 \) – pollution  

(5)

Building the formula of daily relative air pollution indexes (RAPIₙ)

Divide qi from (1) into 3 groups: Group 1 consists of \( m_1 \) parameter(s) having \( q_i = 1 \); Group 2 contains \( m_2 \) parameter(s) having \( q_i < 1 \) and group 3 contains \( k \) parameter(s) having \( q_i > 1 \).

Multiply the two sides of the inequalities \( q_i = 1 \), \( q_i < 1 \), and \( q_i > 1 \) respectively with \( W_i \):

\[ W_i q_i \geq 0 \text{ with } q_i = 1; \quad W_i (1-q_i) > 0 \text{ with } q_i < 1 \text{ and } W_i (q_i - 1) > 0 \text{ with } q_i > 1 \]

From (1) we have:

\[ P_m = \sum_{i=1}^{m_1} W_i q_i + \sum_{i=1}^{m_2} W_i (1-q_i) \]  

(6)

\[ P_k = \sum_{i=1}^{k} W_i (q_i - 1) \]  

(7)

\[ P_n = P_m + P_k \text{ is the total amount of pollution of } n \text{ individual indices} \]  

(8)
Because $P_m/P_n \leq 1$ and $P_k/P_n \leq 1$, so:

$$100 \times \frac{P_m}{P_n} \leq 100 \Rightarrow 100 \times \left(1 - \frac{P_m}{P_n}\right) \geq 0$$

and

$$100 \times \frac{P_k}{P_n} \leq 100 \Rightarrow 100 \times \left(1 - \frac{P_k}{P_n}\right) \geq 0$$

There are two approaches to building aggregate indexes:

Aggregate Pollution Index: The higher the value of RAPI is, the greater the extent of the air pollution is, so on the 100" scale, we have:

$$\text{RAPI}_d = 100 \left(1 - \frac{P_m}{P_n}\right)$$

Aggregate quality index: The smaller the value of RAQI is, the worse the air quality is, so on a scale of 100, we have:

$$\text{RAQI}_d = 100 \left(1 - \frac{P_k}{P_n}\right)$$

Here the author uses the formula (9):

$$\text{RAPI}_d = 100 \left(1 - \frac{P_m}{P_n + P_k}\right)$$

Setting the rating threshold of RAPI

The rating threshold is determined by the following formula:

$$T_m = 100 \left(1 - \frac{m}{n}\right)$$

Use mathematical conditions: infimum (inf), supremum (sup), minimum value, maximum value, average value and median value.

Consider the following cases:

1st case: The bottom of the threshold is 0

When sup (m)=n, that means all survey parameters are lower than the permitted concentration limit, then by formula (12), we have

$$T_m = 100(1-1) = 0$$

2nd case: The upper limit of the threshold is 100

When inf (m)=0, that means all n parameters are higher than the permitted concentration limit

$$T_m = 100(1 - 0) = 100$$

3rd case: Light pollution threshold

When m=max (n)=n - 1, it means that there is n-1 parameter lower than the permitted concentration limit

$$T_m = 100 \left(1 - \frac{n - 1}{n}\right) = \frac{100}{n}$$

4th case: Heavy pollution threshold:
For $n$ positive integers, $m$ is the median of $n$, $n \geq 2$ and $m=0, 1, 2, ...$, so two cases occur:

If $n$ is even, then $m = \frac{n}{2}$, $T_m = 100 \left( 1 - \frac{n}{2n} \right) = 50$ (16)

If $n$ odd, then $m = \frac{n+1}{2}$, $T_m = 100 \left( 1 - \frac{n+1}{2n} \right) = 50 \frac{n-1}{n}$ (17)

5th case: Very heavy pollution threshold:

When $m = \min (n) = 1$, there is only 1 parameter smaller than permitted standard (others are higher than permitted standard), $T_m = 100 \left( 1 - \frac{1}{n} \right) = 100 \times \frac{n-1}{n}$ (18)

6th case: Non-polluted threshold

It is the mean value of the bottom of the threshold and light pollution threshold:

$T_m = \frac{1}{2} \left( 0 + \frac{100}{n} \right) = \frac{50}{n}$ (19)

The evaluation hierarchy of $\text{RAPI}_i$

The set of thresholds (13)-(19) we have the evaluation hierarchy presented in Table 1.

When $n=2$ (even), there are no heavy and very heavy levels of pollution, Table 1 has three levels, where Serious pollution level is defined: $\frac{100}{n} < 1 \leq 100$

When $n=3$ (odd), there is no heavy pollution level, Table 1 has 4 levels, the level of very heavy pollution is defined:

$\frac{100}{n} < 1 \leq \frac{n-1}{n}$

Method of calculating the temporary weights $W'_i$ and final weights $W_i$ of parameters

Temporary weights $C_i^*$ are standardized to convert the $C_i^*$ into non-dimensional. It denotes the relationship of parameters $i$ with standards $j$ (1 h, 8 h and 24 h):

Temporary weights $W'_i$ is calculated by formula:

$$W'_i(S_j) = \frac{\sum_{j=1}^{m} C_i^* (S_j)}{m \times C_i^* (S_j)}$$ (20)

The final weights $W_i$ is calculated by formula:

$$W_i(S_j) = \frac{W'_i(S_j)}{\sum_{j=1}^{n} W'_i(S_j)}$$ (21)
Easy to see: $\sum_{i=1}^{n} W_i = 1$ (22)

Where: $S_j$ = standard of parameter $i$ (1 h/8 h/24 h), $m$ = number of standard, $m$ = 2 or $m$ = 3; $n$ = number of parameter having same standard.

**Frequency of pollution**

To assess the air pollution variations by months in each year, the daily means of the RAPI$_d$ indices are not taken to avoid "virtual" effects occurring. It is necessary to calculate the frequency of $f$ (%) of RAPI$_d$ by month by the following formula:

$$f(\%) = \frac{\text{The total of the RAPI}_d \text{ has the same level of pollution in each month}}{\text{The total of all the RAPI}_d \text{ in each month}} \times 100$$ (23)

**RESULTS AND DISCUSSION**

**Results of calculations**

Place $n=5$ in Table 1, resulting in the rating hierarchy presented in Table 2.

Using the formulas (20)-(22), we have the weights $W'_i$ and $W_i$ presented in Table 3.

It can be seen from Table 4, there is no value $q_i=1$, so formulae (6), (7), (8), (11) are applied and we have:

$$P_m = \sum_{i=1}^{5} W_i \times (1 - q_i) = W_{SO_2}(1h) \times (1 - q_{SO_2}(1h)) + W_{CO}(1h) \times (1 - q_{CO}(1h)) + W_{NO_2}(1h) \times (1 - q_{NO_2}(1h)) + W_{CO}(8h) \times (1 - q_{CO}(8h)) + W_{NO_2}(8h) \times (1 - q_{NO_2}(8h)) + W_{SO_2}(24h) \times (1 - q_{SO_2}(24h)) + W_{NO_2}(24h) \times (1 - q_{NO_2}(24h)) = 0.18 \times (1 - 0.137) + 0.17 \times (1 - 0.156) + 0.2 \times (1 - 0.563) + 0.23 \times (1 - 0.103) + 0.6 \times (1-0.354) + 0.4 \times (1 - 0.102) + 0.41 \times (1 - 0.128) + 0.32 \times (1 - 0.496) = 1.856$$

$$P_k = \sum_{i=1}^{5} W_i(q_i-1) = W_{PM_{10}}(1h) \times (q_{PM_{10}}(1h) - 1) + W_{PM_{10}}(24h) \times (q_{PM_{10}}(24h) - 1) = 0.22 \times (1.389 - 1) + 0.27 \times (1.586 - 1) = 0.244$$

$$P_n = P_m + P_k = 2.100$$

$$RAPI = 100 \times \left(1 - \frac{P_m}{P_n}\right) = 100 \times \left(1 - \frac{1.856}{2.100}\right) = 11.608$$

From Table 2, it can be indicated that air quality is light level.

Above calculation is applied to other days in a similar way.

**Figure 1:** Frequency of air pollution level around the Van Cu station by month by RAPI$_d$ in 2016 [14]
Table 1: Rating scale of RAPI=1

<table>
<thead>
<tr>
<th>n even</th>
<th>n odd</th>
<th>Level of pollution</th>
<th>Color</th>
<th>Warning level to health</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100 \frac{n-1}{n} &lt; 1 \leq 100$</td>
<td>$100 \frac{n-1}{n} &lt; 1 \leq 100$</td>
<td>Serious pollution (Dangerous)</td>
<td>Brown</td>
<td>Serious affected on health</td>
</tr>
<tr>
<td>$50 \frac{n-1}{n} &lt; 1 \leq 100 \frac{n-1}{n}$</td>
<td>$50 \frac{n-1}{n} &lt; 1 \leq 100 \frac{n-1}{n}$</td>
<td>Very heavy pollution (very bad quality)</td>
<td>Red</td>
<td>Very affected on health</td>
</tr>
<tr>
<td>$100 \frac{n}{n} &lt; 1 \leq 50 \frac{n-1}{n}$</td>
<td>$100 \frac{n}{n} &lt; 1 \leq 50 \frac{n-1}{n}$</td>
<td>Heavy pollution (bad quality)</td>
<td>Orange</td>
<td>Affected health</td>
</tr>
<tr>
<td>$50 \frac{n}{n} &lt; 1 \leq 100 \frac{n}{n}$</td>
<td>$50 \frac{n}{n} &lt; 1 \leq 100 \frac{n}{n}$</td>
<td>Light pollution (Fair quality)</td>
<td>Yellow</td>
<td>Affected on the sensitive people</td>
</tr>
<tr>
<td>$0 \leq 1 \leq 50 \frac{n}{n}$</td>
<td>$0 \leq 1 \leq 50 \frac{n}{n}$</td>
<td>No pollution (Good quality)</td>
<td>Green</td>
<td>No affected</td>
</tr>
</tbody>
</table>

Note: Special case

Table 3: Weights of 5 surveyed parameters according to Vietnamese technical regulation 05:2013/MVNRE for standards 1 h, 8 h and 24 h [15]

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter (µg/m³)</th>
<th>Average standard 1 h</th>
<th>Average standard 8 h</th>
<th>Average standard 24 h</th>
<th>$W^*(1\text{ h})$</th>
<th>$W^*(8\text{ h})$</th>
<th>$W^*(24\text{ h})$</th>
<th>$W^h(1\text{ h})$</th>
<th>$W^h(8\text{ h})$</th>
<th>$W^h(24\text{ h})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SO₂</td>
<td>350</td>
<td>-</td>
<td>125</td>
<td>0.67</td>
<td>-</td>
<td>1.90</td>
<td>0.18</td>
<td>-</td>
<td>0.41</td>
</tr>
<tr>
<td>2</td>
<td>CO</td>
<td>30000</td>
<td>10000</td>
<td>-</td>
<td>0.66</td>
<td>2.00</td>
<td>-</td>
<td>0.17</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>NO₂</td>
<td>200</td>
<td>-</td>
<td>100</td>
<td>0.75</td>
<td>-</td>
<td>1.50</td>
<td>0.20</td>
<td>-</td>
<td>0.32</td>
</tr>
<tr>
<td>4</td>
<td>O₃</td>
<td>200</td>
<td>120</td>
<td>-</td>
<td>0.80</td>
<td>1.33</td>
<td>-</td>
<td>0.23</td>
<td>0.40</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>PM₁₀</td>
<td>300</td>
<td>-</td>
<td>200</td>
<td>0.83</td>
<td>-</td>
<td>1.25</td>
<td>0.22</td>
<td>-</td>
<td>0.27</td>
</tr>
</tbody>
</table>

$\sum q_i = 1$  

Note: "-": no requirement

Table 4: Database to calculate the RAPI on 1/1/2016, in which $C_i^\text{Max}(1\text{ h})$, $C_i^\text{Max}(8\text{ h})$ is the highest values of parameter i; $\overline{C}_i(24\text{ h})$ is the average value of parameter i; $q_i$ is the individual index of parameter i

<table>
<thead>
<tr>
<th>No</th>
<th>Parameters (µg/m³)</th>
<th>$C_i^\text{Max}(1\text{ h})$</th>
<th>$q_i(\overline{C}_i(1\text{ h})$ )</th>
<th>$C_i^\text{Max}(8\text{ h})$</th>
<th>$q_i(\overline{C}_i(8\text{ h})$ )</th>
<th>$\overline{C}_i(24\text{ h})$</th>
<th>$q_i(\overline{C}_i(24\text{ h})$ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SO₂</td>
<td>48.06</td>
<td>0.137</td>
<td></td>
<td></td>
<td>15.941</td>
<td>0.128</td>
</tr>
<tr>
<td>2</td>
<td>CO</td>
<td>4686</td>
<td>0.156</td>
<td>3542</td>
<td>0.354</td>
<td>49.576</td>
<td>0.496</td>
</tr>
<tr>
<td>3</td>
<td>NO₂</td>
<td>112.5</td>
<td>0.563</td>
<td></td>
<td></td>
<td>12.24</td>
<td>0.102</td>
</tr>
<tr>
<td>4</td>
<td>O₃</td>
<td>20.6</td>
<td>0.103</td>
<td>12.24</td>
<td>0.102</td>
<td>317.206</td>
<td>1.586</td>
</tr>
<tr>
<td>5</td>
<td>PM₁₀</td>
<td>416.85</td>
<td>1.389</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Frequency of pollution f (%)

Use formula (2), (3), (4), (5), (6), (7) and (8) to calculate RAPId according to Equation (11), then apply formula (23). Results of frequency of pollution f (%) presented on Table 5 and frequency chart of months in 2016 is presented in Figure 1.

**DISCUSSION**

**Comparison by month**

Calculation result based on index RAPI_d shows the air pollution levels according to rating scale from grade I to grade V, of which the RAPI_d has two levels in February, March, June, July, September, October, the RAPI_d values vary from 4 to 96; the RAPI_d has three levels in January, April, May, August, November, the RAPI_d values vary from 3.4 to 83.3, and the RAPI_d has five levels in December with the RAPI_d values vary from 3.4 to 37.9 (Table 5).

**Comparison by season**

Result of RAPI_d shows that the pollution level of ambient air at Nguyen Van Cu station in the dry season (from October to March) is almost worse than the rainy season (from April to September). This matches the physical sense: in the rainy season, radiation intensity, air temperature and humidity in Hanoi are usually higher than in the dry season, therefore the intensity of atmospheric turbulence is strong, causing atmospheric conditions to become unstable, and the air to spread and diffuse intensively into the higher atmospheric layers. In the dry season, radiation intensity, air temperature and humidity in Hanoi are usually lower than in the rainy season, intensity of turbulent exchange is weak, making atmospheric condition either stable or very stable, especially, in cases of high temperature inversion, leading to weak intensity of turbulent diffusion of atmosphere. The pollutants are mainly concentrated in the atmospheric layer close to the ground, which increases the level of pollution on the ground surface in comparison with the rainy season.

**CONCLUSION**

The RAPI_d (Relative Air Pollution Index) has overcome some of the limitations of the API/AQI indices being used in the world and in Vietnam. The RAPI_d rating hierarchy is set based on mathematical conditions: infimum (inf), supremum (sup), minimum value, maximum value), Mean value and median value; The weight of each parameter is calculated according to the standard (1 h, 8 h and 24 h) of each country; The RAPI_d and the frequency of pollution f (%) by month in each year are not affected by virtual effects (Virtual effects includes eclipsing and ambiguity. Eclipsing usually happens with aggregate index which is arimethic means of individual indicies. Therefore, individual indicies are much higher than standard value will be eclipsed by other indicies which are much lower than

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**Table 5. Frequency of air pollution around the station Nguyen Van Cu 2016**

<table>
<thead>
<tr>
<th>Month</th>
<th>I (%)</th>
<th>II (%)</th>
<th>III (%)</th>
<th>IV (%)</th>
<th>V (%)</th>
<th>$\sum f$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>54.8</td>
<td>35.5</td>
<td>9.7</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>85.7</td>
<td>14.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>71</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>60</td>
<td>36.7</td>
<td>3.3</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>3.4</td>
<td>83.3</td>
<td>13.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>96</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>82.6</td>
<td>17.4</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>77.4</td>
<td>12.9</td>
<td>9.7</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>80.8</td>
<td>19.2</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>64.7</td>
<td>35.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>39.3</td>
<td>46.4</td>
<td>14.3</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>10.4</td>
<td>20.7</td>
<td>37.9</td>
<td>27.6</td>
<td>3.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Rainy season (%) | 25 | 59 | 34 | 20 | 0 |
Dry season (%) | 75 | 41 | 66 | 80 | 100 |

$\sum R + D(\%)$ | 100 | 100 | 100 | 100 | 100 |

Note: A rainy season is from April to September, dry season is from October to March
standard values. About ambiguity, it is also aggregate index without considering weight of individual indicies and evaluation hierarchy is self-regulation so the calculated aggregate indicies can be not suitable with the monitoring data). The RAPId can be extended to the number of toxic gas parameters (not the basic parameters) with \( n \geq 2 \), the toxic gas parameters are in the standard of each country.

\( \text{Rapid} \) was calculated experimentally for the Nguyen Van Cu automatic observation station. The results showed that the frequency of pollution \( f(\%) \) was consistent with the level of air pollution around Nguyen Van Cu area (characterizing for ambient air of the traffic areas in Hanoi, Vietnam) for rainy season and dry season in 2016.

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